

SHORT COMMUNICATION

Escapes of non-native fish from flooded aquaculture facilities: the case of Paranapanema River, southern Brazil

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ABSTRACT. Non-native species are a major driver of biodiversity loss. Aquaculture activities play a key role in introductions, including the escape of fishes from fish farm facilities. Here, the impact of flooding due to El Niño rains in 2015/2016 in the Lower and Middle Paranapanema River basin, southern Brazil, was investigated by evaluating fish escapes from 12 fish farms. The flooding resulted in the escape of approximately 1.14 million fishes into the river, encompassing 21 species and three hybrids. Non-native species were the most abundant escapees, especially *Oreochromis niloticus* (Linnaeus, 1758) and *Coptodon rendalli* (Boulenger, 1897) (96% of all fish). Only seven native fishes were in the escapee fauna, comprising 1% of all fish. Large floods, coupled with inadequate biosecurity, thus resulted in considerable inputs of non-native fish into this already invaded system.

KEY WORDS. Biological invasion, climate change, fish farming, Paraná River, propagule pressure.

Freshwater aquaculture is strongly reliant on non-native fish species, which often become a problem when they escape (De Silva et al. 2009, Ortega et al. 2015, Davies and Britton 2016, Pelicice et al. 2017). Several fish species, including the tilapia, e.g. *Oreochromis niloticus* (Linnaeus, 1758), and the common carp, *Cyprinus carpio* Linnaeus, 1758, are cultured globally (Gozlan 2008). In fact more tilapia is produced in their invasive range than in their native African range (Gozlan et al. 2010). Non-native freshwater fish can escape into the basins, especially in facilities that provide no barriers to fish dispersal (Marchini et al. 2008, Ortega et al. 2015, Davies and Britton 2016).

In some countries, especially those with developing economies (e.g., Brazil, Peru, Colombia), priorities are often given to activities that generate revenues, irrespective of whether these could lead to environmental impacts (Gherardi et al. 2011,

Pelicice et al. 2017). In Brazil, for example, whilst legislation is there to protect and limit the use of non-native species in freshwater aquaculture activities (Ayroza et al. 2006), there are public policies that encourage the use of non-native fishes that disregard the impacts these species could have in the neighbouring waterbodies (Lima Junior et al. 2012, Vitule et al. 2012, Orsi and Britton 2014, Pelicice et al. 2014, Casimiro et al. 2015, Lima et al. 2016, Padial et al. 2016, Pelicice et al. 2017).

The release of non-native fish from aquaculture sites occurs through a variety of mechanisms, including their direct stocking into natural systems (Agostinho et al. 2016), the escape of individual fish from open net-cages that are placed in reservoirs in intensive aquaculture systems (Agostinho et al. 2007, Azevedo-Santos et al. 2011), and escapes from ponds built in the margins of rivers that are inundated with water during floods

(Orsi and Agostinho 1999). In Brazilian freshwater aquaculture, fish are frequently cultivated in production ponds located in river margins, with severe floods during the 1996/1997 El Niño resulting in approximately 1.29 million individuals belonging to 11 fish species and one hybrid being released from ponds into the Paranapanema River (Orsi and Agostinho 1999). These escapes were attributed to poor project planning, illegal aquaculture installations and/or farming facilities being inadequately installed in riparian areas prone to floods. Since then, aquaculture activities have increased in the basin in response to the development programs applied by the Brazilian Government (SEAB/DERAL 2016).

Since this major flood event in 1996/97, the risk of fish farms causing further releases of non-native fishes has actually increased due to the Brazilian Forest Code (Law 12,651/12) that reduces the Permanent Preservation Area (Casatti 2010, Magalhães et al. 2011, Forneck et al. 2016). The rainy season of 2015/16 was exceedingly wet in southern Brazil, also a consequence of El Niño rains, and resulted in extreme flooding in the Lower and Middle Paranapanema River basin and that resulted in number of fish farms being inundated with floodwater. The aim of this study was to therefore record the species richness and abundance of non-native fish that escaped during these flood events in 2015/16 to enable comparison with those that occurred in 1996/97.

Information on species richness and number of escaped fish was obtained from interviews conducted at aquaculture sites in the Lower and Middle Paranapanema River that could have been affected by the El Niño floods (Fig. 1). The total number of sites surveyed was 12, comprising eight sites that specialised in fish production (e.g., tilapias) and four sites that specialised in providing angling opportunities for paying anglers ('fish and pay' sites). At each site, structured interviews were used to gather data between April and August 2016 (i.e. in the post-flooding period). These interviews included the following questions: (i) What species are produced on the site? (ii) Were any hybrid forms produced and, if so, between which species? (iii) Were any fishes lost during the El Niño floods and, if so, how many of each species? and (iv) What was the area of production ponds affected (ha)? These data were analysed to determine the fishes being cultivated, the number of individuals that were dispersed into the river by the floods and the total area affected. The geographic locations of the sites were obtained via GPS (Garmin; 5 m accuracy).

The results of the interviews indicated that the number of escaped fish varied considerably between the 12 facilities, ranging between 500 and approximately 1,000,000 individuals, with a total estimate of approximately 1.14 million (M) juvenile and adult fishes released into the wild (Table 1). These fishes belonged to 21 species and three hybrid varieties (Table 1). The main species that escaped were the tilapias *O. niloticus* and *Coptodon rendalli* (Boulenger, 1897), with these comprising 96% of all escaped fishes. Among the 24 fish species released, 14 were

non-native to the upper Paraná River basin, corresponding to 98% of all escapee fish. From the three hybrids detected (7,500 individuals), two had at least one parental non-native fish in the basin: tambacu (*Piaractus mesopotamicus* x *Colossoma macropomum*), and pintachara (*Pseudoplatystoma corruscans* x *Pseudoplatystoma fasciatum*), and one with no parental species native of the basin (jundiara, *Leiarius marmoratus* x *Pseudoplatystoma reticulatum*). Additionally, 400 individuals of two species were recorded as present in the Paranapanema River basin for the first time: pirarucu *Arapaima gigas* (Schinz, 1822) and pirarara *Phractocephalus hemiliopterus* (Bloch & Schneider, 1801) that, both escaped from 'fish and pay' angling. Comparison with data from the flood event in 1996/97 (Orsi and Agostinho 1999) revealed there was an increase in the number of species cultivated, with native species increasing from one to seven species, non-native species from nine to 14 species and hybrid fishes from one to three (Fig. 2). Despite the addition of native species cultivated, the number of individuals belonging to native species still comprised only 1% of all escaped fish in 2015/2016 (Table 1).

These data reveal that the flood events of 2015/16 in the Paranapanema River basin resulted in substantial numbers of non-native fish escaping from aquaculture sites along the river. A new event occurred almost 20 years after a previous flood event that caused a similar effect (Orsi and Agostinho 1999), and nothing was done to prevent further escapes. However, with the relaxation of legislation that previously protected forested riparian areas (Casatti 2010, Magalhães et al. 2011), coupled with increased recreational fishing activities ('fish and pay' facilities) (Fernandes et al. 2008), aquaculture parks (Lima et al. 2016) and the encouraging of the production of non-native species (Law 5989/09) (Pelicice et al. 2014, Casimiro et al. 2015), there was, by consequence, a repeat escape event. This also, indicates that biosecurity measures remained inadequate, allied with inspections by the relevant regulatory authorities not being sufficient to remedy this.

Compared with the study of Orsi and Agostinho (1999) on the 1996/97 flood event when 38 facilities were visited and interviewed, 12 were studied in 2015/16. Yet the estimated absolute number of escapee individual fish was similar (1.14 M versus 1.29 M), suggesting increases in the number of fish produced per facility (Flores and Pedroza-Filho 2014, Forneck et al. 2016, SEAB/DERAL 2016). Massive escapes suggest that the recent modifications in the Brazilian Forest Code that have relaxed controls on the culture around the river has resulted in a substantial risk of spreading cultivated fishes into the wild (Magalhães et al. 2011).

Even the introduction of native species from aquaculture can present risk to wild populations, such as by reducing genetic variability in the population into which they are released (Pereira et al. 2010). Aquaculture may inadvertently decrease the genetic variability present in farmed stocks by the selection and breeding of related specimens or by the use of a small number of parents as

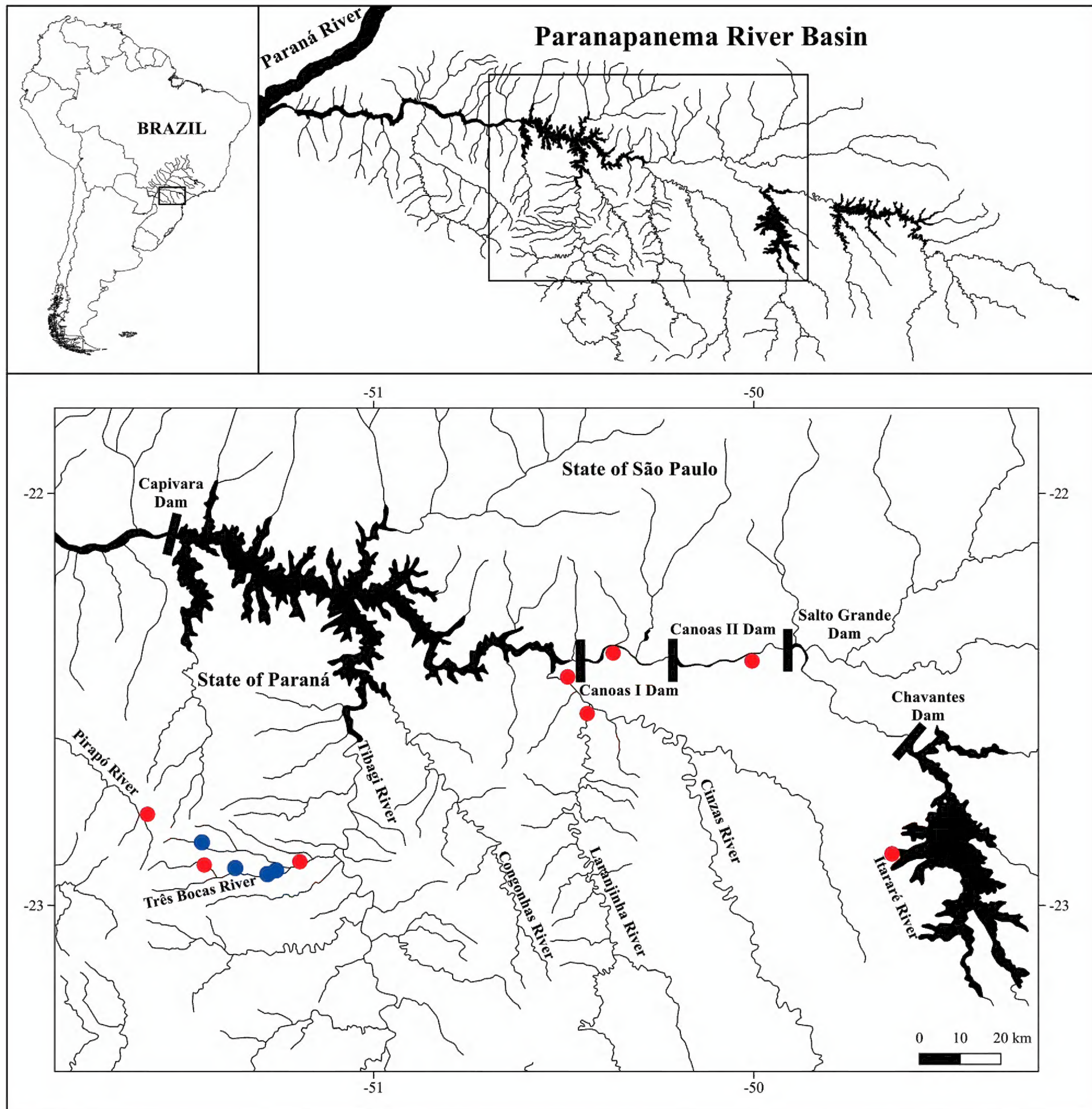


Figure 1. Map of the Paranapanema River basin with the location of the evaluated areas (red dots: fish production, blue dots: 'fish and pay').

brood stock (Kostow 2009, Almeida et al. 2013). The introduction risk is compounded by a range of additional consequences that non-native fishes can have in the wild, including altered habitat structure, hybridization, disease transmission, and increased trophic interactions (e.g. predation and competition) that can lead all negatively impact native fauna (Agostinho et al. 2007, Vitule et al. 2009, Ashikaga et al. 2010, Alves et al. 2014).

The decreased controls of the production of non-native fish species in Paranapanema River basin over the last twenty years have also been concomitant with an increase in the number of 'fish and pay' sites. These are fisheries used for angling that are mainly stocked with large-bodied fishes to maximise angler attraction and satisfaction, with species used including *A. gigas*, *P. hemiliopterus*, *P. fasciatum*, and *Colossoma macropo-*

Table 1. Absolute (relative) abundance and origin of fish species and hybrids registered in the escapes from fish ponds of the Paranapanema River basin during the flood of 2015/2016. Classification and origin are based on Eschmeyer (2017). *Non-native species, **unquantified species.

	Common name	Abundance	Region of origin
Cypriniformes			
Cyprinidae			
<i>Cyprinus carpio</i> Linnaeus, 1758*	Common carp	2100 (0.18)	Asia
Characiformes			
Prochilodontidae			
<i>Prochilodus lineatus</i> (Valenciennes, 1837)	Curimba	500 (0.04)	Paraguay, Paraná and Paraíba do Sul River basins
Anostomidae			
<i>Megaleporinus macrocephalus</i> (Garavello & Britski, 1988)	Piauçu	2500 (0.22)	Paraguay and Lower Paraná River basins
<i>Leporinus</i> spp.	Piau	2700 (0.24)	uncertain
Bryconidae			
<i>Salminus brasiliensis</i> (Cuvier, 1816)	Dourado	1000 (0.09)	Paraguay, Paraná and Uruguay River basins
<i>Brycon falcatus</i> Müller & Troschel, 1844*	Matrinxã	8500 (0.74)	Brazilian and Guyana shields, western Amazon and Orinoco River basins
<i>Brycon orbignyanus</i> (Valenciennes, 1850)	Piracanjuba	500 (0.04)	Upper Paraná River basin
Serrassalmidae			
<i>Colossoma macropomum</i> (Cuvier, 1816)*	Tambaqui	2000 (0.18)	Amazon and Orinoco River basins
<i>Piaractus mesopotamicus</i> (Holmberg, 1887)	Pacu	11760 (1.03)	Paraguay and Paraná River basins
Salmonidae			
<i>Salmo trutta</i> Linnaeus, 1758*	Brown trout	200 (0.02)	Europe
Arapaimidae			
<i>Arapaima gigas</i> (Schinz, 1822)*	Pirarucu	200 (0.02)	Amazon River basin
Siluriformes			
Heptapteridae			
<i>Leiarius marmoratus</i> (Gill, 1870)*	Jundiá	1000 (0.09)	Amazon, Essequibo and Orinoco River basins
Pimelodidae			
<i>Pseudoplatystoma fasciatum</i> (Linnaeus, 1766)*	Cachara	300 (0.03)	Paraguay and Lower Paraná River basins
<i>Pseudoplatystoma corruscans</i> (Spix & Agassiz, 1829)	Pintado	2300 (0.20)	São Francisco and Paraná River basins
<i>Phractocephalus hemioliopus</i> (Bloch & Schneider, 1801)*	Pirarara	200 (0.02)	Amazon and Orinoco River basins
Clariidae			
<i>Clarias gariepinus</i> (Burchell, 1822)*	African catfish	3000 (0.26)	Central Africa
Ictaluridae			
<i>Ictalurus punctatus</i> (Rafinesque, 1818)*	Channel catfish	2000 (0.18)	North America
Gymnotiformes			
Gymnotidae			
<i>Gymnotus</i> spp.	Tuvira	1000 (0.09)	uncertain
Labriformes			
Cichlidae			
<i>Cichla</i> spp.*	Peacock bass	500 (0.04)	Amazon River basin
<i>Oreochromis niloticus</i> (Linnaeus, 1758)*	Nile Tilapia	765030 (66.95)	Africa
<i>Coptodon rendalli</i> (Boulenger, 1897)*	Tilapia	327870 (28.69)	Africa
Hybrids			
<i>Colossoma macropomum</i> × <i>Piaractus mesopotamicus</i>	Tambacu	1500 (0.13)	Amazon and Orinoco River basins x Upper Paraná River basin
<i>Leiarius marmoratus</i> × <i>Pseudoplatystoma reticulatum</i>	Jundiara	**	Amazon, Essequibo and Orinoco River basins x Amazon and Lower Paraná River basins
<i>Pseudoplatystoma corruscans</i> × <i>Pseudoplatystoma fasciatum</i>	Pintachara	6000 (0.53)	Upper Paraná River basin x Paraguay and Lower Paraná River basins

mum (Cuvier, 1816). Although the ecological consequences of these fishes in the wild remain uncertain, they are potentially very high, given these fishes tend to be large-bodied piscivores. Indeed, the predators, such as *A. gigas* and *P. hemioliopus*, can have substantial structuring impacts on native species (Barbarino-Duque and Winemiller 2003, Pelicice and Agostinho 2009, Miranda-Chumacero et al. 2012, Van Damme et al. 2015, Ribeiro et al. 2017).

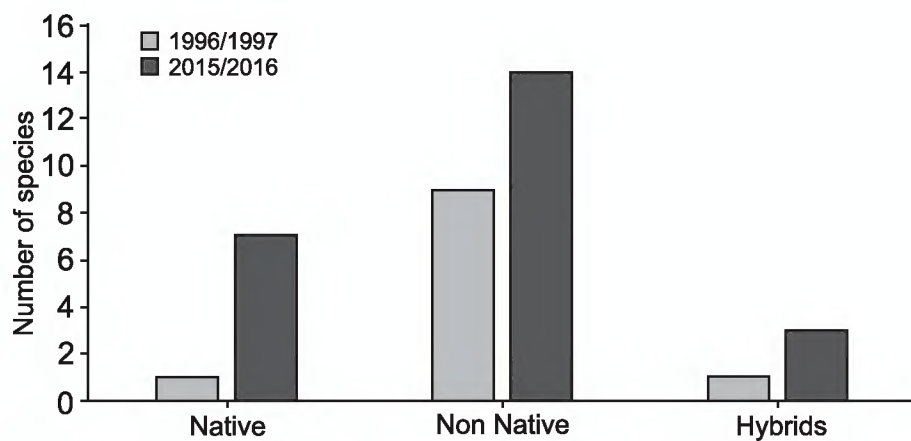


Figure 2. Number of fish species escaped (native, non-native and hybrid) in the Lower and Middle Paranapanema River basin during the floods of 1996/1997 (Orsi and Agostinho 1999) and 2015/2016.

In summary, the escapes of non-native and native fish from aquaculture and fishery activities in the Paranapanema River basin that occurred due to flooding during El Niño rains represent a high propagule pressure in a basin that is already invaded by a number of non-native fishes (Britton and Orsi 2012). If these unscheduled releases can be prevented in future, then environmental control agencies such as Brazilian Institute of Environment and Renewable Natural Resources (IBAMA) should work together with aquaculturists, fry producers, aquaculture associations, ‘fish and pay’ owners, and conservationists to find optimal solutions. Solutions could include: (i) application of the precautionary principle or ‘polluter pays’ principle to minimise the risk of escapee fish entering the wider environment; (ii) increase of pond embankment height to prevent escape of the species during periods of flooding; and (iii) construction of containment structures that provide some biosecurity during inundation events. These recommendations would help Brazilian government to meet its international commitments in controlling non-native species whilst ensuring aquaculture can continue high rates of fish production and maintain food supplies without losing their stock during flood events. With the increase of aquaculture in Brazil, if these protection recommendations are not considered, new escapes of non-native fishes into the basin are likely to be a re-occurring issue, especially during future flood events.

LITERATURE CITED

- Agostinho AA, Gomes LC, Pelicice FM (2007) Ecologia e manejo de recursos pesqueiros em reservatórios do Brasil. EDUEM, Maringá, 501 pp.
- Agostinho AA, Gomes LC, Santos NC, Ortega JC, Pelicice FM (2016) Fish assemblages in Neotropical reservoirs: Colonization patterns, impacts and management. *Fisheries Research* 173: 26–36. <https://doi.org/10.1016/j.fishres.2015.04.006>
- Almeida FS, Lopes CM, Orsi ML, Sirol RN, Sodr   LMK (2013) Genetic monitoring by RAPD markers for repopulation programs of *Salminus brasiliensis* (Pisces, Characiformes). *Acta Scientiarum Animal Sciences* 35: 119–126. <https://doi.org/10.4025/actascianimsci.v35i2.15904>
- Alves AL, Varela ES, Moro GV, Kirschnik LNG (2014) Riscos Gen  ticos da Produ  o de H  bridos de Peixes Nativos. Embrapa Pesca e Aquicultura, Palmas, 60 pp.
- Ashikaga FY, Casimiro ACR, Kurchevski G, Almeida FS, Orsi ML (2010) Invas  o dos h  bridos nas  guas continentais brasileiras. *Boletim da Associa  o Brasileira de Limnologia* 38: 1–5.
- Ayroza DMMR, Furlaneto FPB, Ayroza LMS (2006) Regulariza  o dos projetos de tanques-redes em  guas p blicas continentais de dom nio da Uni  o no Estado de S o Paulo. *Boletim T cnico do Instituto de Pesca* 36: 1–32.
- Azevedo-Santos VM, Rigolin-S  O, Pelicice FM (2011) Growing, losing or introducing? Cage aquaculture as a vector for the introduction of nonnative fish in Furnas Reservoir, Minas Gerais, Brazil. *Neotropical Ichthyology* 9: 915–919. <https://doi.org/10.1590/S1679-62252011000400024>
- Barbarino-Duque A, Winemiller KO (2003) Dietary segregation among large catfishes of the Apure and Arauca Rivers, Venezuela. *Journal of Fish Biology* 63: 410–427. <https://doi.org/10.1046/j.1095-8649.2003.00163.x>
- Britton JR, Orsi ML (2012) Non-native fish in aquaculture and sport fishing in Brazil: economic benefits versus risks to fish diversity in the upper River Paran  Basin. *Reviews in Fish Biology and Fisheries* 22: 555–565. <https://doi.org/10.1007/s11160-012-9254-x>
- Casatti L (2010) Altera  es no C digo Florestal Brasileiro: impactos potenciais sobre a ictiofauna. *Biota Neotropica* 10: 31–34. <https://doi.org/10.1590/S1676-06032010000400002>
- Casimiro ACR, Garcia DAZ, Vidotto-Magnoni AP, Vitule JRS, Orsi ML (2015) Biodiversity: is there light for native fish assemblages at the end of the Anthropocene tunnel? *Journal of Fish Biology* 89: 4–49. <https://doi.org/10.1111/jfb.12847>
- Davies GD, Britton JR (2016) Assessment of non-native fish dispersal from a freshwater aquaculture site. *Fisheries Management and Ecology* 23: 428–430. <https://doi.org/10.1111/fme.12176>
- De Silva SS, Nguyen TTT, Turchini GM (2009) Alien species in aquaculture and biodiversity: a paradox in food production. *Ambio* 38: 24–28. <https://doi.org/10.1579/0044-7447-38.1.24>
- Fernandes R, Gomes LC, Agostinho AA (2008) Pesque-pague: neg cio ou fonte de dispers o de esp cies ex ticas? *Acta Scientiarum Biological Sciences* 25: 115–120. <https://doi.org/10.4025/actascibiolsci.v25i1.2089>
- Flores RMV, Pedroza-Filho MX (2014) Is the internal market able to accommodate the strong growth projected for Brazilian aquaculture? *Journal of Agricultural Science and Technology* 4: 407–417.
- Forneck SC, Dutra FM, Zacarkim CE, Cunico AM (2016) Invasion risks by non-native freshwater fishes due to aquaculture activity in a Neotropical stream. *Hydrobiologia* 773: 193–205. <https://doi.org/10.1007/s10750-016-2699-5>
- Gherardi F, Britton JR, Mavuti KM, Pacini N, Grey J, Tricarico E, Harper DM (2011) A review of allodiversity in Lake Naivasha, Kenya: Developing conservation actions to protect East African lakes from the negative impacts of alien species. *Biological Conservation* 144: 2585–2596.

- Gozlan RE (2008) Introduction of non-native freshwater fish: is it all bad? *Fish and Fisheries* 9: 106–115. <https://doi.org/10.1111/j.1467-2979.2007.00267.x>
- Gozlan RE, Britton JR, Cowx I, Copp GH (2010) Current knowledge on non-native freshwater fish introductions. *Journal of Fish Biology* 76: 751–786. <https://doi.org/10.1111/j.1095-8649.2010.02566.x>
- Kostow K (2009) Factors that contribute to the ecological risks of salmon and steelhead hatchery programs and some mitigating strategies. *Reviews in Fish Biology and Fisheries* 19: 9–31. <https://doi.org/10.1007/s11160-008-9087-9>
- Lima Junior DP, Pelicice FM, Vitule JRS, Agostinho AA (2012) Aquicultura, Política e Meio Ambiente no Brasil: Novas Propostas e Velhos Equívocos. *Natureza e Conservação* 10: 88–91. <https://doi.org/10.4322/natcon.2012.015>
- Lima LB, Oliveira FJM, Giacomini HC, Lima-Junior DP (2016) Expansion of aquaculture parks and the increasing risk of non-native species invasions in Brazil. *Reviews in Aquaculture* 0: 1–12. <https://doi.org/10.1111/raq.12150>
- Magalhães ALB, Casatti L, Vitule JRS (2011) Alterações no Código Florestal Brasileiro favorecerão espécies não-nativas de peixes de água doce. *Natureza & Conservação* 9: 121–123. <https://doi.org/10.4322/natcon.2011.017>
- Marchini A, Savini D, Occhipinti-Ambrogi A (2008) Aquaculture and alien species in the EU-Med region. Part II: dispersal risk into the wild. *Biologic Marine Mediterranea* 15: 234–235.
- Miranda-Chumacero G, Wallace R, Calderón H, Calderón G, Willink P, Guerrero M, Teddy M, Siles TM, Lara K, Chuqui D (2012) Distribution of arapaima (*Arapaima gigas*) (Pisces: Arapaimidae) in Bolivia: implications in the control and management of a non-native population. *BiolInvasions Records* 1: 129–138. <https://doi.org/10.3391/bir.2012.1.2.09>
- Orsi ML, Agostinho AA (1999) Introdução de espécies de peixes por escapes acidentais de tanques de cultivo em rios da Bacia do Rio Paraná, Brasil. *Revista Brasileira de Zoologia* 16: 557–560. <https://doi.org/10.1590/S0101-81751999000200020>
- Orsi ML, Britton JR (2014) Long-term changes in the fish assemblage of a neotropical hydroelectric reservoir. *Journal of Fish Biology* 84: 1964–1970. <https://doi.org/10.1111/jfb.12392>
- Ortega JCG, Júlio Jr HF, Gomes LC, Agostinho AA (2015) Fish farming as the main driver of fish introductions in Neotropical reservoirs. *Hydrobiologia* 746: 147–158. <https://doi.org/10.1007/s10750-014-2025-z>
- Padial AA, Agostinho AA, Azevedo-Santos VM, Frehse FA, Lima-Junior DP, Magalhães ALB, Mormul RP, Pelicice FM, Bezerra LAV, Orsi ML, Petrere-Junior M, Vitule JRS (2016) The “Tilapia Law” encouraging non-native fish threatens Amazonian River basins. *Biodiversity and Conservation* 26: 243–246. <https://doi.org/10.1007/s10531-016-1229-0>
- Pelicice FM, Agostinho AA (2009) Fish fauna destruction after the introduction of a non-native predator (*Cichla kelberi*) in a Neotropical reservoir. *Biological Invasions* 11: 1789–1801. <https://doi.org/10.1007/s10530-008-9358-3>
- Pelicice FM, Vitule JRS, Lima Junior DP, Orsi ML, Agostinho AA (2014) A serious new threat to Brazilian freshwater ecosystems: the naturalization of nonnative fish by decree. *Conservation Letters* 7: 55–60. <https://doi.org/10.1111/conl.12029>
- Pelicice FM, Azevedo-Santos VM, Vitule JRS, Orsi ML, Lima Junior DP, Magalhães ALB, Pompeu PS, Petrere Jr M, Agostinho AA (2017) Neotropical freshwater fishes imperilled by unsustainable policies. *Fish and Fisheries* 0: 1–15. <https://doi.org/10.1111/faf.12228>
- Pereira JC, Lino PG, Leitão A, Joaquim S, Chaves R, Pousão-Ferreira P, Guedespinto H, Neves SM (2010) Genetic differences between wild and hatchery populations of *Diplodus sargus* and *D. vulgaris* inferred from RAPD markers: implications for production and restocking programs design. *Journal of Applied Genetics* 51: 67–72. <https://doi.org/10.1007/BF03195712>
- Ribeiro VR, Leandro da Silva PR, Gubiani ÉA, Faria L, Daga VS, Vitule JRS (2017) Imminent threat of the predator fish invasion *Salminus brasiliensis* in a Neotropical ecoregion: eco-vandalism masked as an environmental project. *Perspectives in Ecology and Conservation* 15: 132–135. <https://doi.org/10.1016/j.pecon.2017.03.004>
- SEAB/DERAL (2016) Secretaria da Agricultura e do Abastecimento/ Departamento de Economia Rural. Piscicultura: Análise e Conjuntura. Available on line at: <http://www.agricultura.pr.gov.br/modules/conteudo/conteudo.php?conteudo=239> [Accessed: 27/05/2017]
- Van Damme PA, Coca Méndez C, Zapata M, Carvajal-Vallejos FM, Carolsfeld J, Olden JD (2015) The expansion of *Arapaima cf. gigas* (Osteoglossiformes: Arapaimidae) in the Bolivian Amazon as informed by citizen and formal science. *Management of Biological Invasions* 6: 375–383. <https://doi.org/10.3391/mbi.2015.6.4.06>
- Vitule JRS, Freire CA, Simberloff D (2009) Introduction of non-native freshwater fish can certainly be bad. *Fish and Fisheries* 10: 98–108. <https://doi.org/10.1111/j.1467-2979.2008.00312.x>
- Vitule JRS, Freire CA, Vazquez DP, Nuñez MA, Simberloff D (2012) Revisiting the potential conservation value of non-native species. *Conservation Biology* 26: 1153. <https://doi.org/10.1111/j.1523-1739.2012.01950.x>

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